MODULE – III

Binary phase diagrams (a) Isomorphism system, (b) Eutectic system, (c) Peritectic system, (d)Eutectoid system and (e) Peritectoid system. Allotropic transformation. Lever rule and its application, Interpretation of solidification behaviors and microstructure of different alloys belonging to those systems, Effect of non-equilibrium cooling, coring and homogenization. Iron-cementite and iron-graphite phase diagrams, microstructure and properties of different alloys (alloy steels; stainless steel, tool steel, HSS, high strength low alloy steel) types of cast iron, their microstructures and typical uses Specification of steel.

MODULE - III

↳ The equilibrium diagram is a map which gives relationship betⁿ phases in equilibrium in a system as a function of temp., Pressure, and composition. Equilibrium diagrams also called constitutional diagrams illustrate the stable states of a metal, or alloys i.e. those phases which have lowest free energy under heating/Cooling condition.

↳ The Changes in no. of phases in an alloy under equilibrium Conditions are expressed by Gibb's phase rule.

$\boxed{F = C - P + 2}$

F = No. of degrees of freedom
C = No. of components present in system
P = No. of Phases " "

↳ Here 2 is for two different parameters, those are temp. & Pressure. Normally as Pressure remain constant during heating or cooling, the formula can be modified as

$\boxed{F = C - P + 1}$

↳ **Degree of freedom**: It is the no. of variables which can be changed independently without bringing out disappearance of a phase or formation of new phase.

↳ **Phase**: It is a physically distinct, chemically homogeneous and mechanically separable region of a system

↳ **Components**: It refer to the smallest no. of stable individual substances which describe completely the Chemical composition of system at a temp. or press.

Q: Estimate the degrees of freedom of a three component system with various no. of possible phases.

No. of Phases.	Degree of freedom = C-P+2
1	4
2	3
3	2
4	1
5	0

A 3-component system cannot have more than 5 Phases in equilibrium.

Binary Phase Diagrams

Binary phase diagrams are based on two component systems. Here two components may be mixed in an infinite no. of different proportions, i.e. composition also becomes a variable apart from press. & temp. Pressure maintained 1 atm i.e. pressure made const. $\therefore F = C-P+1$

Some simple type of behaviour can be ~~treated indivi~~ Classified as:

1. Two components are completely soluble in liquid state:

   Type I. And are completely soluble in solid state (Isomorphous)

   Type II. And are completely insoluble in solid state (Eutectic)

   Type III. And are partially soluble in solid state (Eutectic)

   Type IV. Illustrate peritectic reaction

   Type V. And show Syntectic reaction

2. Two components are partially soluble in liquid state. (Monotectic rx^n)

3. Two components are insoluble as well as solid state.

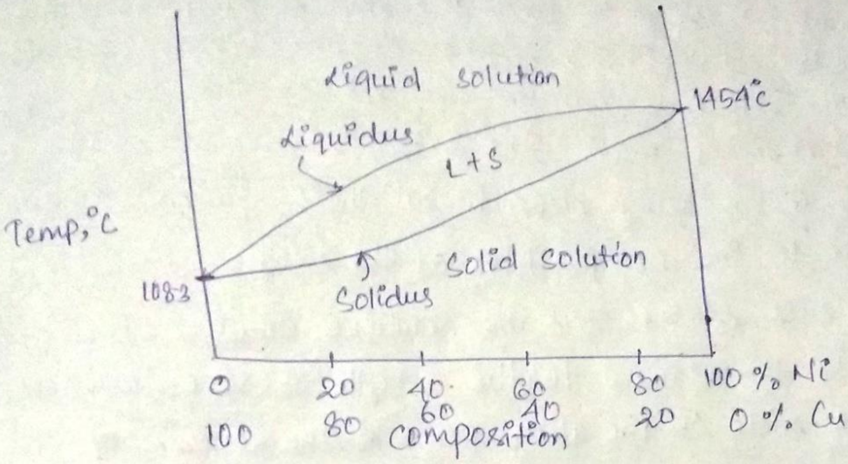
4. Solid State transformations:

   Eutectoid rx^n, peritectoid rx^n.

1 Isomorphous System

This is the case when two metals (in metallic systems) are completely soluble in each other in all proportions, both in the liquid and the solid states, this is also called isomorphous, because only a single type of crystal structure is obtained for all ratios of the components i.e. they form substitutional solid solutions in all proportions.

Example



[Cu-Ni isomorphous system]

Prediction of Phases :

A phase diagram can be used to obtain again the original data used in drawing it. That means, for a definite composition of an alloy and at a definite temp., it is possible, under equilibrium conditions to know i) the phases present there, ii) chemical composition of phases and iii) the amount of each phase.

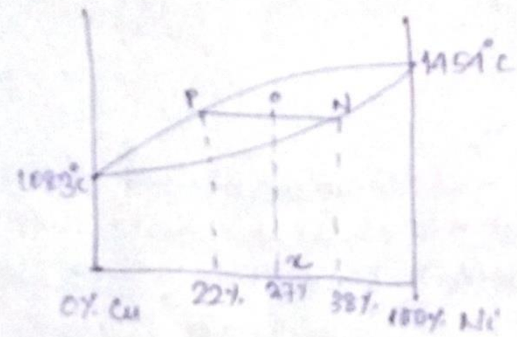
Upper line connecting the points at which freezing begins called liquidus line and it's lower line called solidus line. The area above liquidus line is a single phase region and any alloy in that region will consist of a homogeneous liquid solution. Also, the area below the ~~solution~~ solidus line in a single phase region and any alloy in this region will consist of a homogeneous solid solution. Between liquidus and solidus line there exists a two phase region, which is a mixture of liquid & solid solution. (1-2-1 rule)

It's examples are Ag-Au, Ag-Pt, Cu-Ni, Au-Cu, Au-Ni

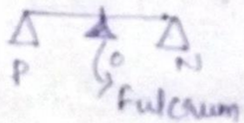
Prediction of Amount of Phases : Lever Rule

Lever rule is used to find the amount of phases present in only the two-phase regions of the binary equilibrium diagram. This rule can be derived on the basis of conservation of mass. The relative amount of the two phases in an alloy depends on their chemical composition relative to the composition of the alloy.

Lever rule states that the relative amount of a given phase is proportional to the length of lever arm on the opposite side of the alloy point of the lever.



At x point what is the amount of phase



Fraction of solid $= \frac{OP}{NP} = \frac{27-22}{38-22} = \frac{5}{16} = 0.3125$

% wt. of solid $= 0.3125 \times 100 = 31.25\%$

Fraction of Liquid $= \frac{NO}{NP} = \frac{38-27}{38-22} = \frac{11}{16} = 0.6875$

% wt. of liquid $= 0.6875 \times 100 = 68.75\%$

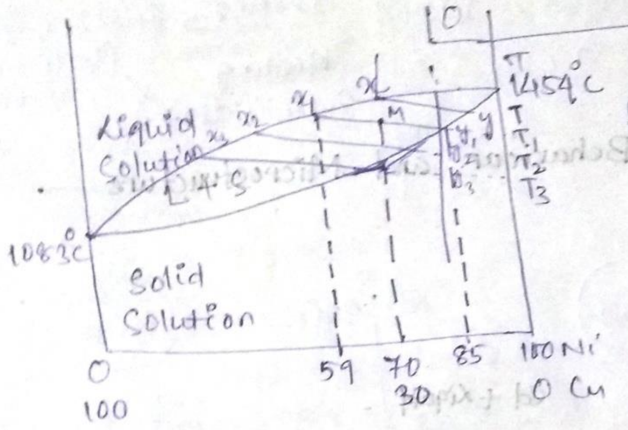
or, % wt. of liquid $= 100 - 31.25 = 68.75\%$

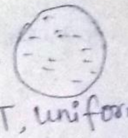
Lever rule can also be applied when two solid phases are present under equilibrium conditions.

This rule cannot be applied at an invarient temp. as 3 phases are in equilibrium. It can be applied above or below invarient temp.

The point where $f = 0$, is called invariant point
$f = 1$, is called univariant "
$f = 2$, is " bivariant " .

Interpretation of Solidification behaviour and microstructure:-
Equilibrium cooling (even heating) means a very slow rate of change of temp. so that at all times, equilibrium cond's are maintained in the system.





Above T, uniform liquid (70Ni 30Cu)

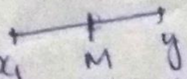
At T, nuclei form of composition y

At T_1, homogeneous dendrites of composition y_1 and liquid of x_1

At T_2, homogeneous dendrites of composition y_2 & liquid of x_2.

Below T3, homogeneous solid solution of composition y_3 (x) = 70Ni 30 Cu

Lets find out amount of solid and liquid present at T_1 temp. where our lever arm is $x_1 M y_1$.



Fraction of solid $= \frac{x_1 M}{x_1 y_1} = \frac{70-59}{85-59}$
$= 0.4231 = 42.31\%$

Fraction of liquid $= 100 - 42.31$
$= 57.69\%$

2. Eutectic Systems

In eutectic systems we can see two different cases.

i) Two components are completely soluble in liquid state and are completely insoluble in each other in solid state.

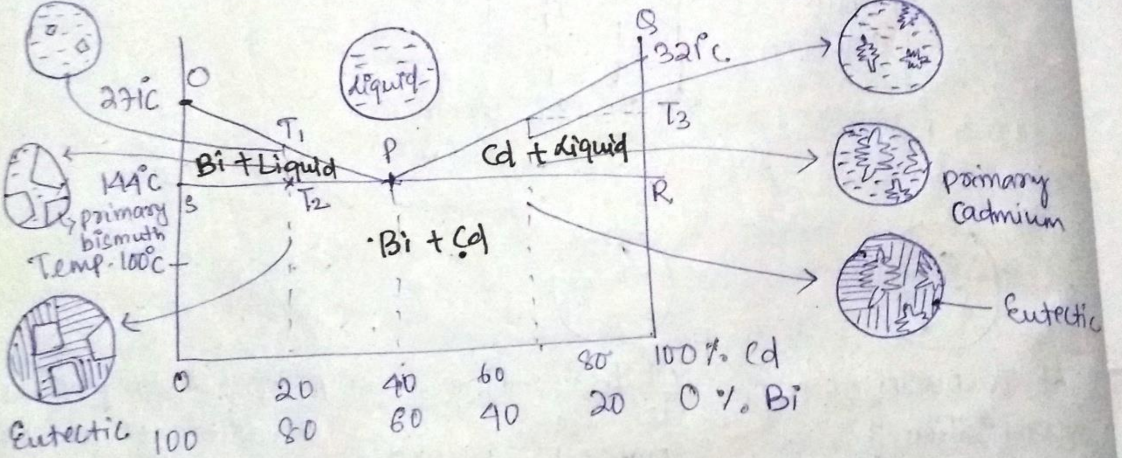
ii) Two components are completely soluble in liquid state and are partially soluble in solid state. Cu-Ag, Pb-As

Example of eutectic systems: Bi-Cd, Al-Si, Pb-Sn, etc.

Equation of reaction: Liquid $\underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftharpoons}}$ Solid 1 + Solid 2 (Eutectic mixture)
(Eutectic temp.)

Solidification Behaviour and Microstructure —

i) Bi - Cd System:



Melting point of Bismuth = 271°C

Melting point of Cadmium = 321°C

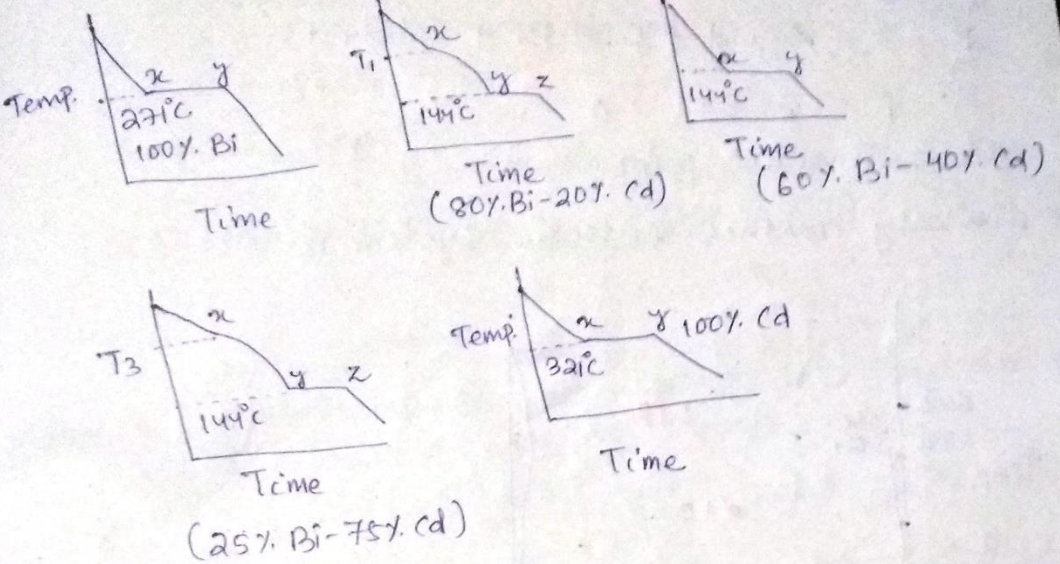
Eutectic temp. = 144°C

At eutectic point, composition is 60% Bi + 40% Cd

Reaction is L (60% Bi, 40% Cd) $\xrightarrow[\text{eutectic temp.}]{144°C}$ Pure Bi + Pure Cd (eutectic mixture)

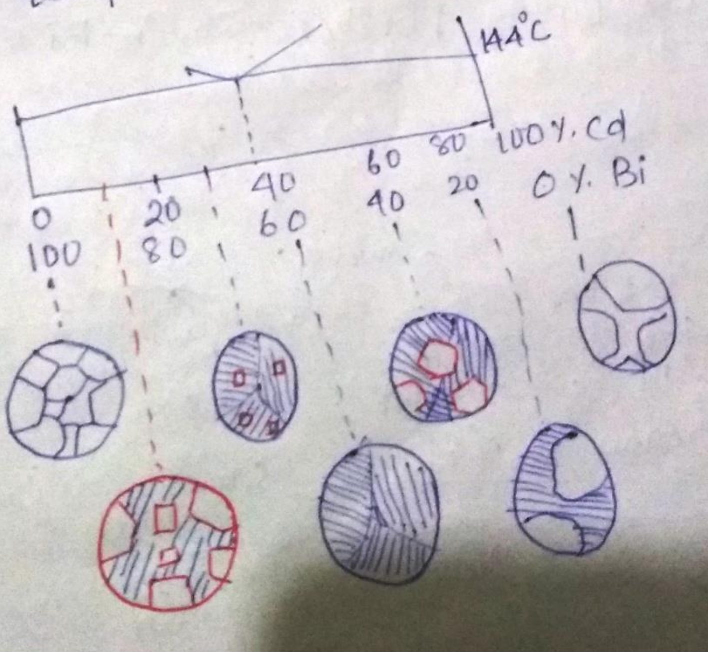
It is clear from the phase diagram that the freezing point of both the pure metals are lowered by addⁿ of second metal. The depression in freezing points is proportional to the molecular wt. of solute metal.

Cooling curve of alloy (Bi-Cd System) at different composition:



'P' is the eutectic point.
Region POS (Left to eutectic point) is known as hypo-eutectic and. PQR Region (Right to eutectic point) is known as hypereutectic.
Wt. of Solid pure Cd or Bi, which solidified before eutectic reaction takes place is called primary Cd or primary Bi (Or proeutectic Cd or Bi).

At room temp. microstructures of different alloys—



At eutectic point (144°c) what is the degree of freedom

$F = C - P + 1$

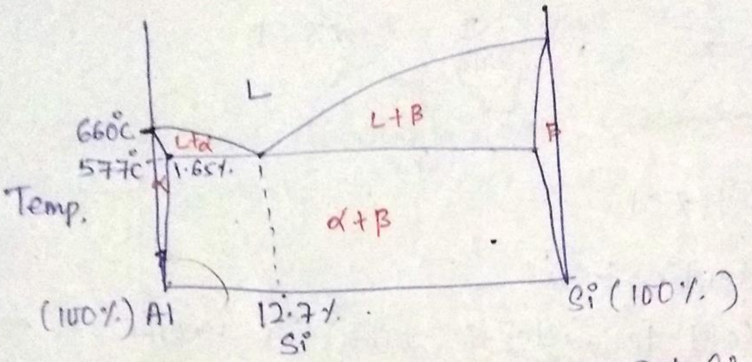
$C = 2$ (Bi & Cd),

$P = 3$ (Liquid + Solid Bi + Solid Cd)

$\therefore F = 2 - 3 + 1 = 0$

This is invarient point.

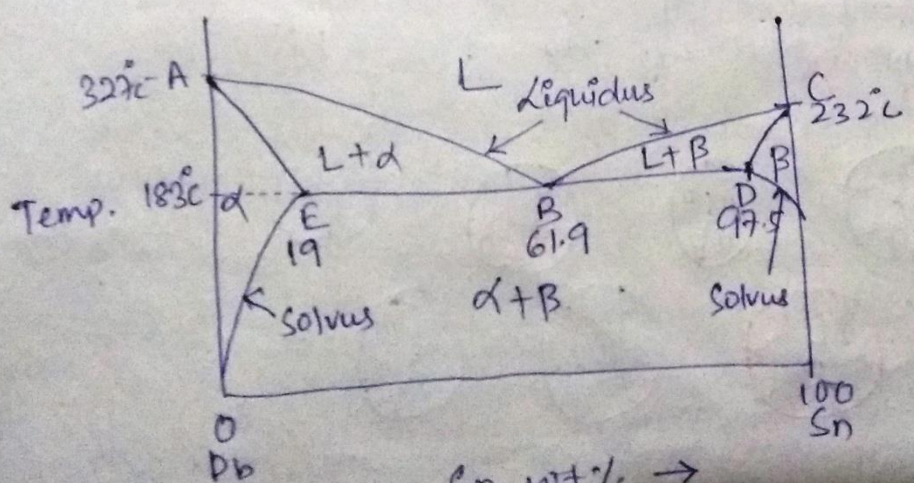
Similarly another eutectic system is Al-Si :



The eutectic composition is 12.7% Si, temp. is 577°c. At this temp. max^m solubility of Si in Al is 1.65%. α is almost pure Al. (Proeutectic solid phase similarly as β)

ii) Two components are completely soluble in liquid state and are partially soluble in solid state

Ex: Pb-Sn, Cu-Ag, Pb-Sb, Cd-Zn, Sn-Bi etc.



[Pb-Sn phase diagram]

ABC line is liquidus, CDBEA is solidus.

α = Solid phase at left end, which is solid solution of Sn in Pb.

β = Solid phase at right end, which is solid solution of Pb in Sn.

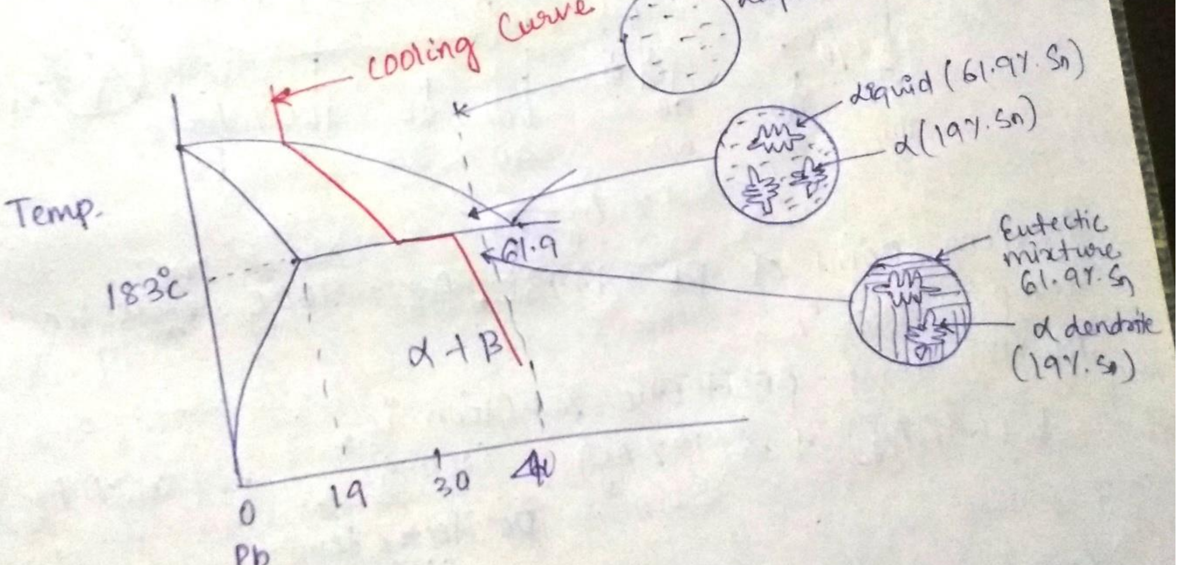
Eutectic Reaction:

$$\underset{(61.9\%\ Sn,\ 38.1\%\ Pb)}{\text{Liquid}} \xrightarrow[\substack{T_e \\ (183^\circ C)}]{\text{Cooling}} \underbrace{\underset{(19\%\ Sn,\ 81\%\ Pb)}{\alpha} + \underset{(97.5\%\ Sn,\ 2.5\%\ Pb)}{\beta}}_{\text{eutectic mixture}}$$

Eutectic temp. can be used as 'tie line' and we can find out amount of phases.

$$\therefore \alpha = \frac{DB}{DE} = \frac{97.5-61.9}{97.5-19} \times 100 = 45.35\%$$

$$\beta = \frac{BE}{DE} = \frac{61.9-19}{97.5-19} \times 100 = 54.65\%$$



Degree of freedom at 183°C,

$$F = C-P+1 = 2-3+1 = 0$$

Above 183°C, degree of freedom,

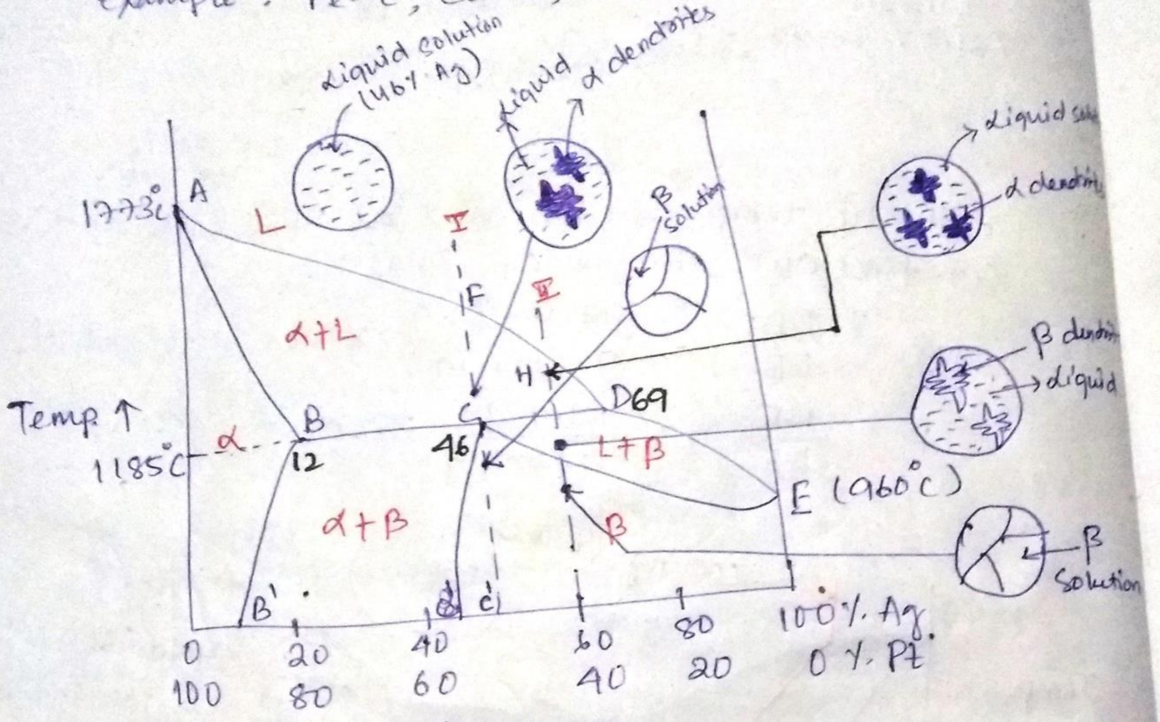
$$F = C-P+1 = 2-2+1 = 1$$

3. PERITECTIC SYSTEM

Peritectic system forms a solid, which is usually an intermediate phase.

$$L\text{ (fixed composition)} + S_1\text{ (fixed composition)} \xrightarrow[\text{Temp.}]{\text{Peritectic}} S_2\text{ (fixed composition)}$$

Example : Fe-C, Cu-Zn, Pt-Ag etc.



Melting point of Pt = 1773°C, Ag = 960°C. Peritectic temp. = 1185°C.

At this temp. peritectic reaction is,

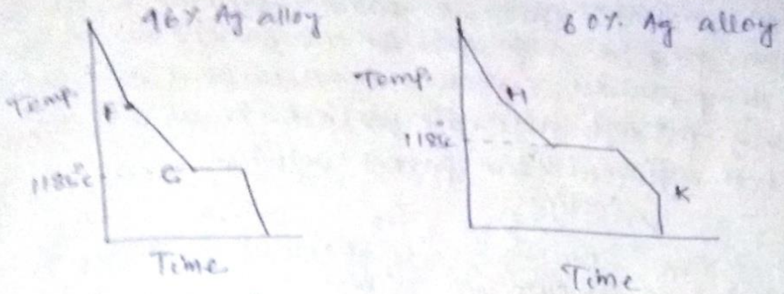
$$L(69\%\,Ag) + \alpha(12\%\,Ag) \xrightarrow[\text{peritectic temp. (1185°C)}]{\text{Cooling}} \beta(46\%\,Ag)$$

Lever rule can be used to calculate amount of phases at a fraction of degree higher than peritectic temp.,

$$\text{Liquid}, \ = \frac{46-12}{69-12} \times 100 = 59.65\%,$$

$$\alpha, \ = \frac{69-46}{69-12} \times 100 = 40.35\%.$$

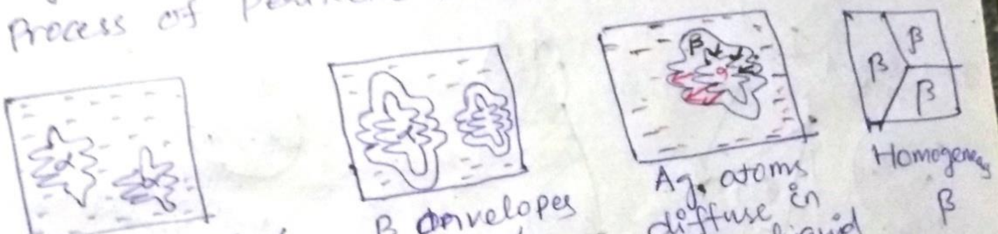
Cooling Curve



(For I line) (For II line)

Right region to peritectic point is 'hypoperitectic' & left region to " " is known as 'hyperperitectic'.

Process of Peritectic reaction at peritectic temp.:-



dendrites of α — β envelopes α. — Ag atoms diffuse in from liquid — Homogeneous β

↳ The liquid and α-phase react here to produce β-phase. β-phase forms at the surface of dendrites of α & very soon α-phase gets enveloped by covering of β-phase. Further growth of β-phase is possible as a result of diffusion of Pt atoms from α-phase & of Ag atoms from liquid to inside. Thus this change to get homogeneous β grains takes place.

↳ For complete peritectic reaction to occur i.e. to get 100% product β-phase in the solid alloy by $\frac{59.65}{40.35}$.

↳ If an alloy has more liquid and α at peritectic temp. should be extra phase remains unreacted along with the product β phase after peritectic rx^n.

4. EUTECTOID SYSTEM

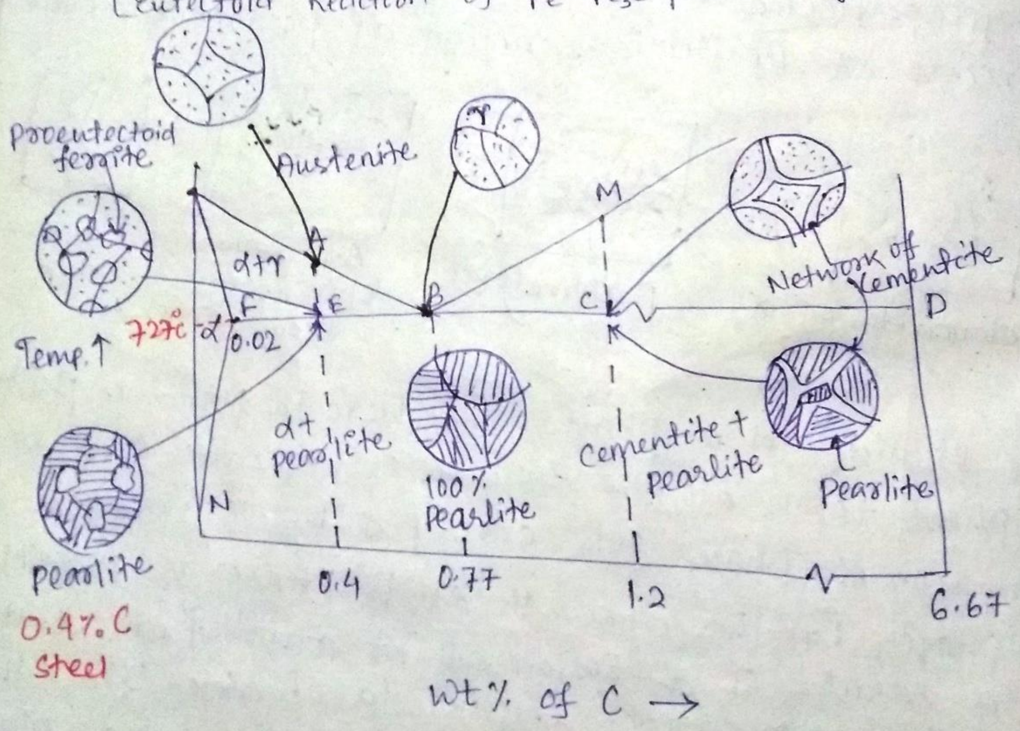
Eutectoid reaction is similar to eutectic reaction, but involves only solids. Here a solid solution up on cooling to some critical temp., called eutectoid temp. is seen to transform completely through alternate precipitation of two solid phases, both different from parent solution.

$$S_1 \xrightleftharpoons[\text{Heating at eutectoid temp.}]{\text{Cooling}} S_2 + S_3$$

S_1 (Solid one of fixed composition)
S_2 (Solid two of fixed composition)
S_3 (Solid three of fixed composition)

Example – Ag-Cd, Ag-Ga, Al-Mn, Au-Zn, Be-Cu, Cu-Zn, Cu-Sn, Cu-Si, Cu-Sb etc.

[Eutectoid Reaction of Fe-Fe_3C phase diagram]



↳ Eutectoid Reaction in Fe-Fe_3C Phase diagram is

$$\underset{(0.77\%C)}{\gamma\ (\text{Austenite})} \xrightarrow[\text{Eutectoid Temp.}]{\text{Cooling}} \underset{(0.02\%C)}{\alpha,\text{Ferrite}} + \underset{(6.67\%C)}{Fe_3C\ (\text{Cementite})}$$

↳ The eutectoid mixture of ferrite and cementite is called pearlite with alternate lamella phases.

↳ Left to eutectoid point is known as 'hypoeutectoid'
Right to eutectoid point is known as 'hypereutectoid'
Lever rule can be used to calculate the amount of these phases in mixture (pearlite) by using FBD as 'tie-line'

α-ferrite (0.02% C), wt % $= \frac{DB}{DF} \times 100$

$= \frac{6.67-0.77}{6.67-0.02} \times 100$

$= 88.7\%$

Fe_3C (6.67% C), wt % $= \frac{BF}{DF} \times 100$

$= \frac{0.77-0.02}{6.67-0.02} \times 100$

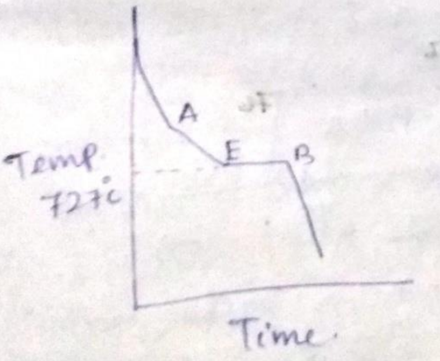
$= 11.3\%$

Amount of ferrite and austenite can be calculated just above eutectoid temp. by using tie-line FEB.

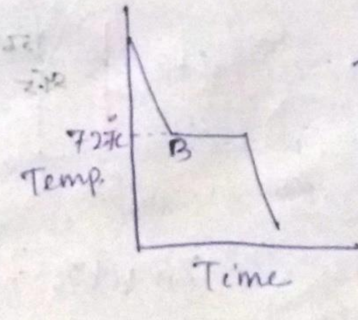
γ (0.77% C) wt% $= \frac{0.4-0.02}{0.77-0.02} \times 100 = 50.67\%$

Ferrite (0.02% C) wt % $= \frac{0.77-0.4}{0.77-0.02} \times 100 = 49.33\%$

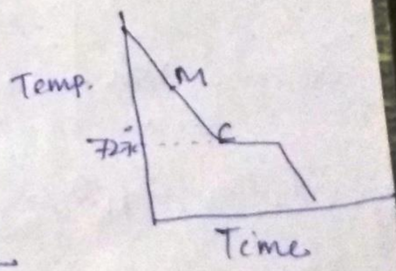
At 0.4 wt % C cooling curve



At 0.77 wt% C cooling curve



At 1.2 wt %. cooling curve



proeutectoid cementite, wt % $= \frac{1.2-0.77}{6.67-0.77} \times 100 = 7.29\%$

Austenite (0.77%C) wt % $= \frac{6.67-1.2}{6.67-0.77} \times 100 = 92.71\%$

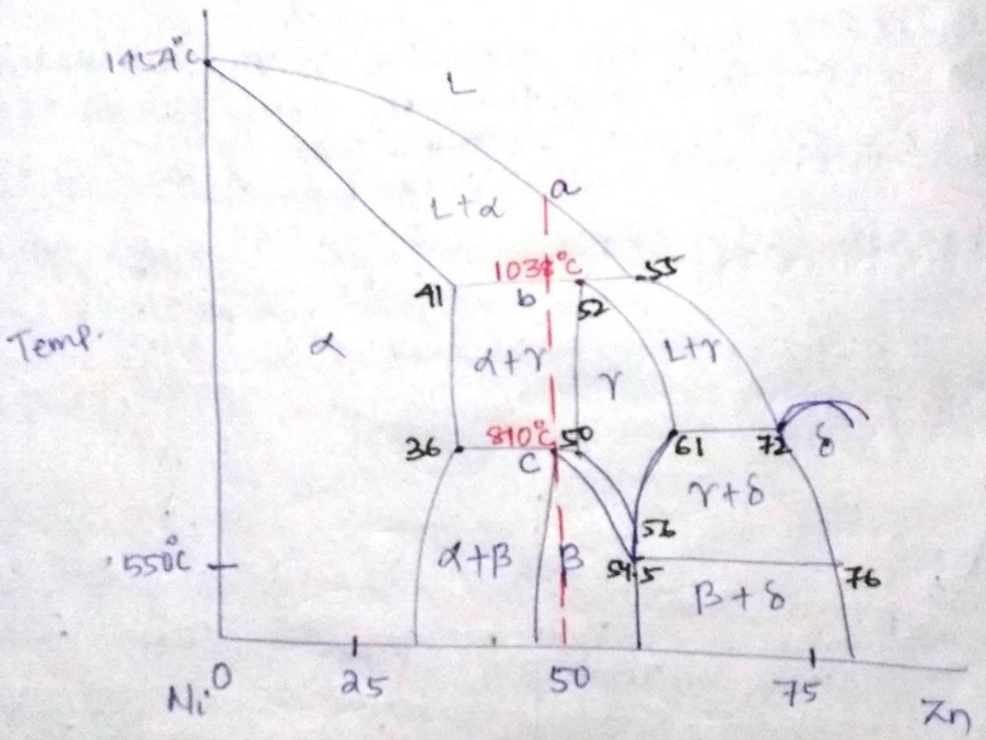
5. PERITECTOID SYSTEM

It occurs in solid state, due to thermal instability of a specific phase. The peritectoid reaction is given by

S_1 (Solid one of fixed composition) + S_2 (Solid two of fixed composition) $\xrightarrow[\text{peritectoid temp.}]{\text{Cooling}}$ S_3 (Solid three (New) of fixed composition)

Example - Ni-Zn, Fe-Cb, Cu-Sb, Cu-Si, Cu-Sn, Ni-Mo, Ni-Si, Fe-Au systems.

[Ni-Zn System]



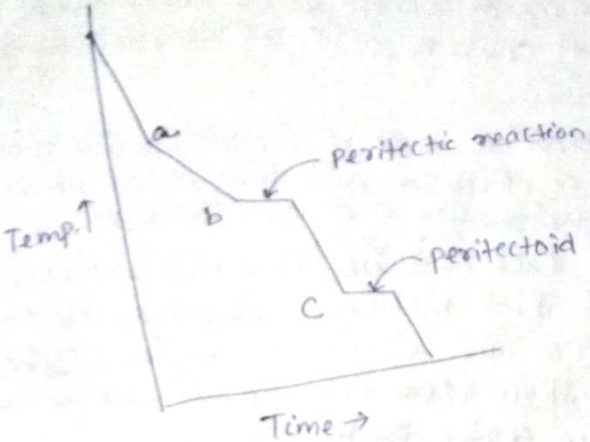
In the above Ni-Zn equilibrium phase diagram two types of reactions are occuring, i) peritectic & ii) peritectoid reaction.

At 1038°C peritectic rxn occuring i.e.

$$L + \alpha \rightarrow \gamma$$

Whereas at 810°C peritectoid rxn is occuring.

Cooling Curve



Lever rule can be used to calculate amount of α and γ present just before peritectoid temp. 810°C is reached:

$$\alpha\ (36\%\ Zn),\ wt\% = \frac{50-48}{50-36} \times 100 = 14.29\%$$

$$\gamma\ (50\%\ Zn),\ wt\% = \frac{48-36}{50-36} \times 100 = 85.71\%$$

Uses of Phase Diagrams :—

i) To predict the temp. at which freezing, melting begins or ends for any specific alloy composition in an alloy system.

ii) To predict safe temp. of working.

iii) Determine no. of phases, types of phases, composition of given alloy at specified temp.

iv) To calculate relative amount of phases present in a two phase alloy.

v) To describe freezing or melting of an alloy.

vi) To predict microstructure of an alloy at any given temp.

vii) To predict possible heat treatment which can be given.

viii) To choose appropriate composition to develop best properties.

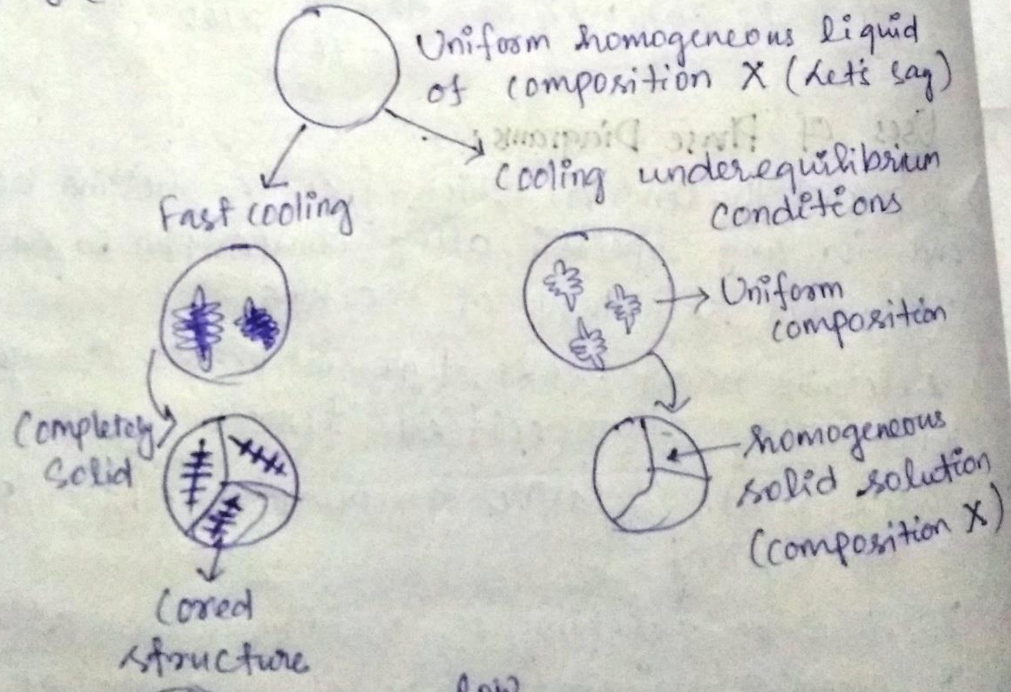
Effect of Nonequilibrium Cooling, Coring and Homogenization

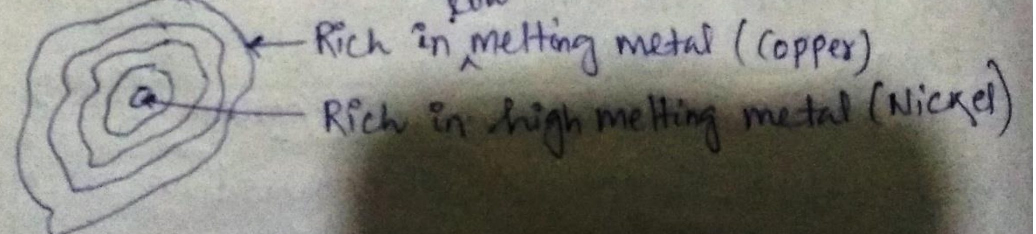
↳ The equilibrium solidification of a solid solution alloy, can be explained using equilibrium phase diagrams, where rate of cooling is <u>infinitely slow</u>. So that complete equilibrium by means of convection (in the liquid) & diffusion (in solid) could be achieved at each stage of process.

↳ Under actual conditions rate of solidification is much faster than rate of diffusion and thus solid phase is unable to attain uniformity and equilibrium.

↳ Core (centre) of each dendrite (or a grain) contains higher amount of high melting metal than the surface of the dendrite (or inter-dendritic region). This variation of composition from core of dendrite to the interdendritic space ~~continuously from the core to~~ is called dendritic segregation. Dendritic-segregation on a microscopic scale is called coring.

↳ Effect of nonequilibrium cooling of solid solution alloy (70Ni 30Cu).





↳ Coring
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↳ Coring takes place in all types of equilibrium diagram. Fast cooling lowers solidus line. Greater the gap between liquidus and solidus, more pronounced is the coring, which becomes still intense if the temp. of freezing of alloys are low. Though diffusivity of both types of atoms at such temp. is important, but normally it is very slow.

↳ Coring frequently results in weakness and brittleness of castings, because of different composition near the grain boundaries.

This problem can be solved by i) Use of slow cooling rates during solidification of alloys, ii) Homogenization of cored castings.

Homogenization of cored casting:

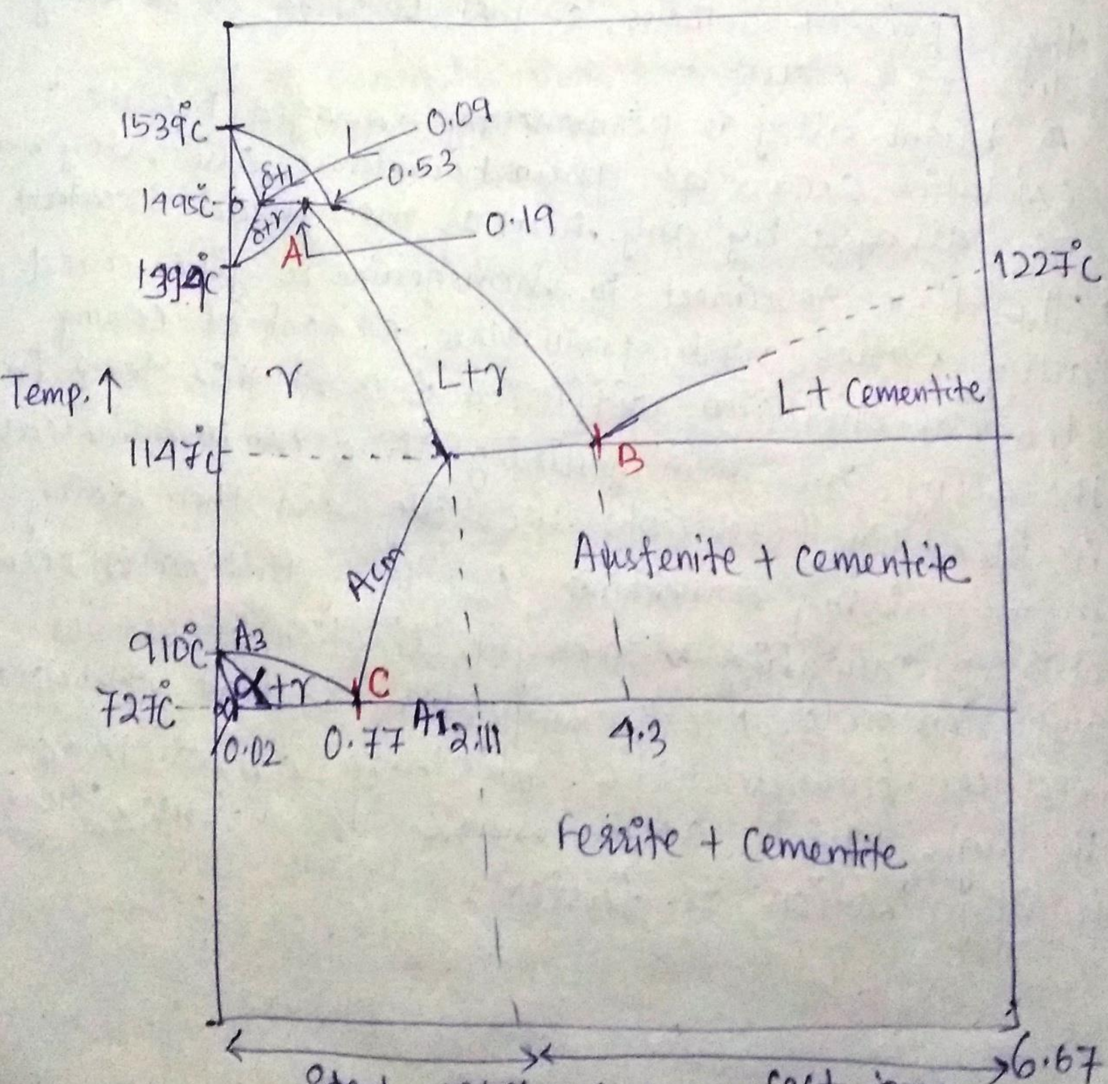
↳ Homogenization is a prolonged annealing treatment at a temp. high enough so that diffusion within the alloy is relatively rapid, but still safely below the depressed solidus, so that burning of the alloy does not occur.

↳ A burnt alloy is permanently damaged, because oxidation occurs at grain boundaries. The alloy cannot be salvaged by any heat or mechanical treatment.

↳ The time required to homogenize a given cored alloy varies with grain size, extent of coring, temp. of diffusion, diffusion rate at this temp. in the alloy. The homogenizing time can in some cases reduced by first cold-working and then doing homogenising annealing. As recrystallization occurs during annealing & recrystallization increases diffusion rate. More important is that cold working reduces interdendritic distance i.e. distance through which atoms have to diffuse. Thus homogenization is faster.

Iron- Cementite Phase diagram 10 marks

- Carbon is the most important alloying element in iron which significantly affects the allotropy, structure and properties of iron. The study of Fe-C system is thus, important, more so as it forms the basis of commercial steels, cast irons and many of the basis features of this system influence behaviour of even the most complex steels.
- Cementite, chemical formula Fe_3C, has a fixed carbon content of 6.67% i.e. when iron has 6.67% Carbon, then 100% cementite is obtained. Thus this diagram which has components iron and cementite can rightly be called as <u>iron- Cementite diagram</u>.
- This is <u>not a true equilibrium diagram</u>, since equilibrium means no change of phase with time however long it may be.



There are different phases in Fe-Fe$_3$C diagram as follows —

i. Alpha ferrite (α) : It is an interstitial solid solution of carbon in α-iron and is BCC structure. Maximum solubility of carbon in ferrite is 0.02% at 727°C.

ii. Austenite (γ) : It is an interstitial solid solution of carbon in γ- iron. It has FCC structure. Max^n solubility of carbon in austenite is 2.11% at 1147°C.

iii. Delta ferrite (δ) : It is an interstitial solid solution of carbon in δ- iron and is BCC structure. Max^n solubility of carbon in iron is 0.09% at 1495°C.

iv. Cementite (Fe$_3$C): It is an interstitial intermediate compound having a fixed carbon content 6.67%. It is orthorhombic crystal structure. It's melting point is nearly 1227°C.

Three important invarient reactions in Fe-Fe$_3$C diagram:-

i: Peritectic Reaction

$$L + S_1 \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftarrows}} S_2$$

In Fe-Fe$_3$C phase diagram point 'A' shown is the peritectic reaction.

$$\underset{(0.53\%C)}{L} + \underset{(0.09\%C)}{\delta\text{- Ferrite (BCC)}} \xrightarrow[\text{Cooling}]{1495°C} \underset{(0.19\%C)}{\gamma\text{-austenite (FCC)}}$$

Left to peritectic point, the steels are known as "hypo-peritectic ~~alloys~~ steel" whereas right to peritectic point is known as "hyper peritectic steel".

$$\text{Liquid, wt\% } (0.53\%\ C) = \frac{0.19-0.09}{0.53-0.09} \times 100 \simeq 18.18\%$$

$$\delta\text{-ferrite, wt\% } (0.09\%C) = \frac{0.53-0.19}{0.53-0.09} \times 100 \simeq 81.82\%$$

ii. **Eutectic Reaction :**

An eutectic invarient reaction in general is

$$L \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftarrows}} S_1 + S_2$$

In Fe-Fe_3C phase diagram point 'B' as shown is the eutectic reaction point. Here the reaction is

$$\underset{(4.3\% C)}{L} \underset{\text{Cooling}}{\overset{1147^\circ C}{\rightleftarrows}} \underset{(2.11\% C)}{\text{Austenite (FCC)}} + \underset{(6.67\% C)}{\text{Cementite (Ortho-rhombic)}}$$

This eutectic mixture is known as Ledeburite.

Alloy containing carbon more than 2.11% is known as cast iron and below is steel.

So here carbon between 2.11 - 4.3% are called 'hypoeutectic cast iron' & betn 4.3-6.67% is 'hypereutectic cast iron'.

Lever rule can be used to calculate the amount of austenite and cementite in the eutectic alloy just after the eutectic rxn, i.e. just below 1147°C.

$$\text{Austenite (of 2.11\% C)} = \frac{6.67 - 4.3}{6.67 - 2.11} \times 100$$

$$= 51.97\%$$

$$\text{Cementite} = \frac{4.3 - 2.11}{6.67 - 2.11} \times 100 = 48.03\%$$

Imp.

iii. **Eutectoid Reaction :**

The eutectoid invarient reaction is a solid state version of eutectic reaction and in general can be represented by an equation :

$$S_1 \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftarrows}} S_2 + S_3$$

In Fe-Fe_3C phase diagram point 'C' is eutectoid reaction.

$$\underset{(\text{of } 0.77\% C)}{\text{Austenite (FCC)}} \underset{\text{Cooling}}{\overset{727^\circ C}{\longrightarrow}} \underset{(\text{of } 0.02\% C)}{\text{Ferrite (BCC)}} + \underset{(\text{of } 6.67\% C)}{\text{Cementite}}$$

Eutectoid mixture is known as pearlite because of its pearly appearance under optical microscope. Fe-0.77%C alloy is called eutectoid steel.

Amount of ferrite and cementite in pearlite at slightly below eutectoid temp. is (727°C)

$$\text{Ferrite (of } 0.02\%C) = \frac{6.67-0.77}{6.67-0.02} \times 100$$

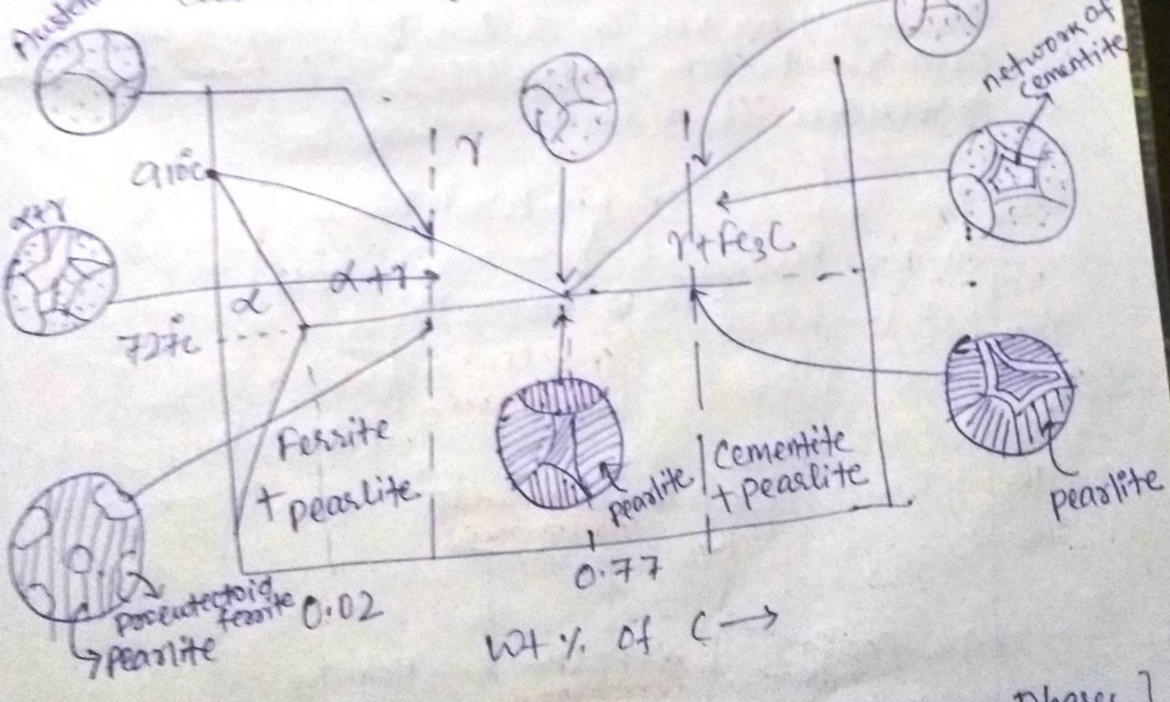
$$= 89\%$$

$$\text{Cementite} = \frac{0.77-0.02}{6.67-0.02} \times 100 = 11\%.$$

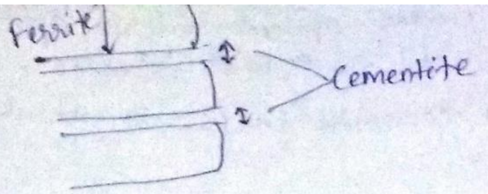
The wt. of these two phases are 89% & 11% respectively, hence their ratio maintained as 8:1. Thus ferrite lamella is 8 times thicker than cementite lamella.

Steels having carbon content betn 0.02-0.77% are called hypoeutectoid steel and 0.77-2.11% are known as hypereutectoid steel.

Eutectoid Region of Fe-Fe3C diagram :-



[Microstructure at different Phases.]

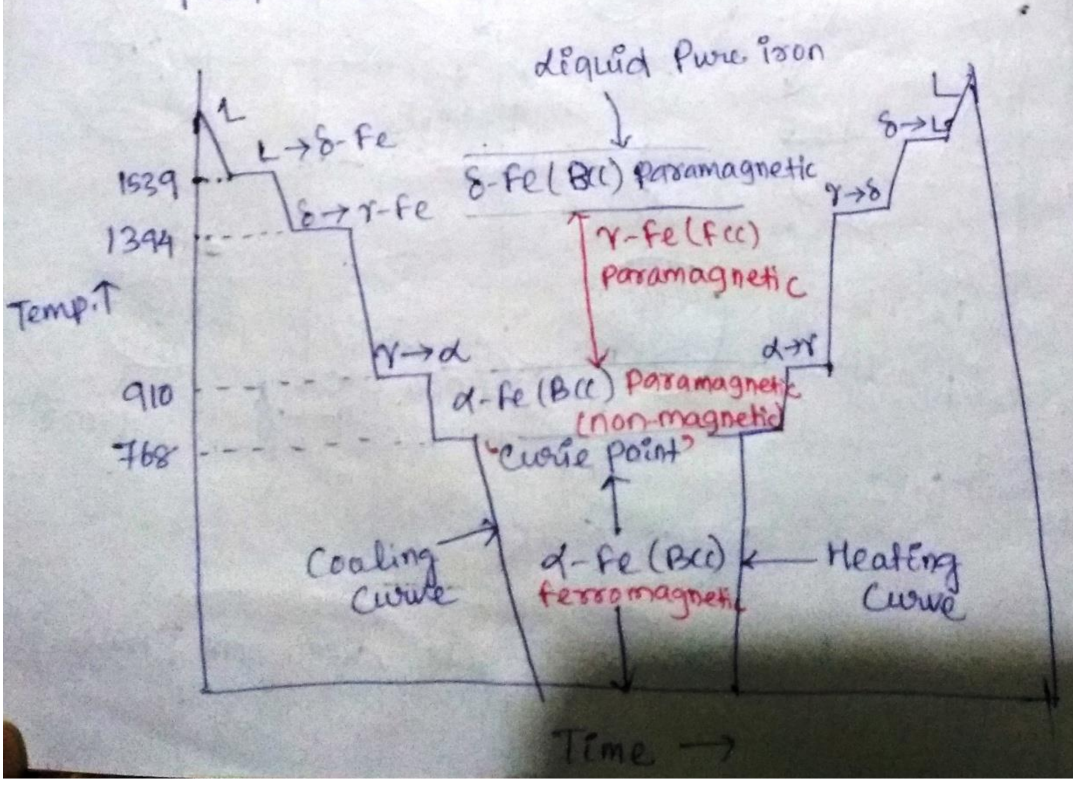


(Alternate lamella of ferrite and cementite in 8:1 ratio in Pearlite)

Allotropic Transformation

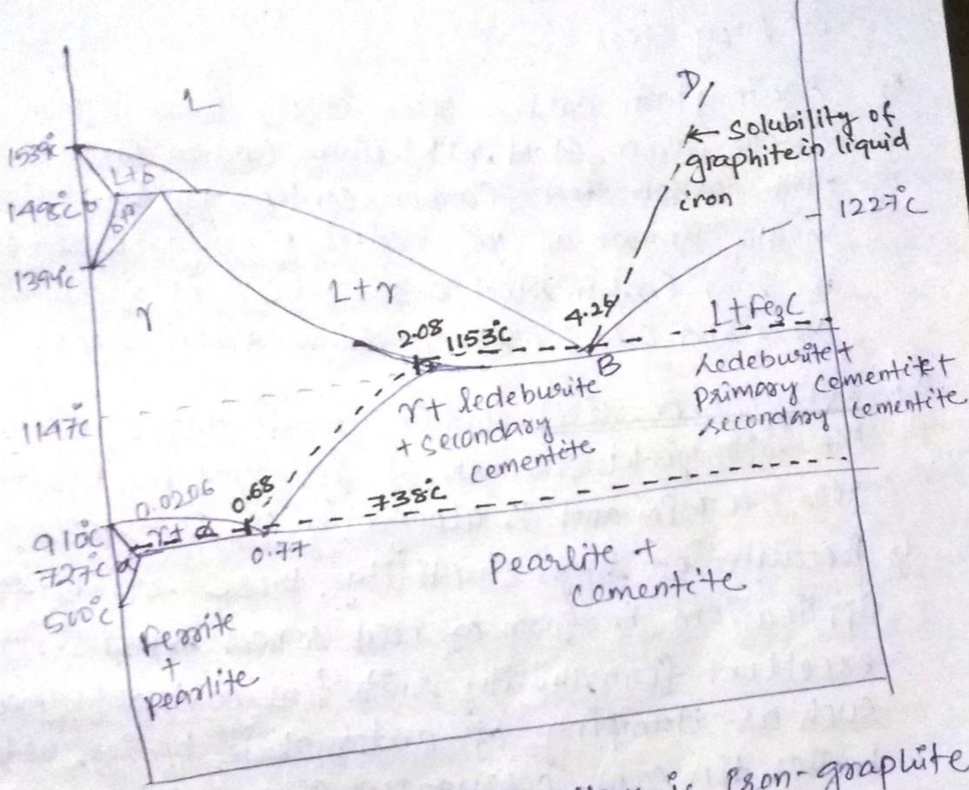
↳ Allotropy can be defined as different physical forms of a chemical substance.

Example: Iron is an allotropic metal: at atmospheric pressure it may exist in more than one crystal structure depending on the temp. Pure iron has essentially two crystalline forms, one BCC, commonly called α-iron i.e. stable at low temp. up to 910°C when it changes to FCC, called γ-iron & stable at 910–1394°C. when it reverts to δ-iron, it is BCC structure. α & δ-iron are not independent modification of iron as they have same crystal structure & the physical properties of δ-Fe are the high temp version of that ~~of~~ α-iron & can be extrapolated from temp. dependence of ~~mean volume~~ properties of α-iron.



Curie temp. :- This is the temp. where ferromagnetic ferrite changes to paramagnetic on heating i.e. at 768°C.

Iron- Graphite Diagram



↳ The stable diagram for Fe-C alloys is Iron-graphite diagram. (The dashed line). Graphite, being the stable phase may form as a result of direct precipitation from liquid or by the decomposition of previously formed cementite, process called graphitization.

↳ Primary graphite starts to solidify at temp. represented by BD'. The eutectic now of austenite and graphite forms at 1153°C. Eutectoid reaction occurs at 738°C. Eutectoid mixture is ferrite + graphite.

Microstructure and Properties of different alloys (Alloy steels; Stainless steel, tool steel; HSS, High Strength low alloy steel.)

When wt% of carbon lies up to 1.8%, we categorize it as steel. It is of two types.

i) Plain carbon steel

ii) Alloy steel

↳ Again plain carbon steel is of three types. a) Low carbon steel, b) Medium carbon steel and c) High carbon steel. Carbon content up to 0.15% is mostly known as mild steel, whereas 0.15 - 0.35% C is low carbon steel, 0.35 - 0.65% is medium carbon steel and 0.65 - 1.8% is high carbon steel.

a) Low carbon steel contain about 0.1% C with 0.3-0.4% Mn with yield strength of 200-300 MPa, tensile strength 300-370 MPa and % elongation of 28-40%.

↳ Because of high ductility, these steels find applications in form of cold rolled ~~steel~~ sheets. Their excellent formability suits for cold deformed shapes such as stampings of automobile bodies, refrigerator bodies, tin cans, corrugated sheets etc.

b) Medium carbon steels have higher strength but lower ductility than low carbon steel. These are hypoeutectoid steel. These steels are often used in normalised condition for a great variety of components in major industries, such as camshafts, connecting rods, gears, friction disc, piston rods, cross pieces, plungers etc.

c) High carbon steels are heat treated steels to attain high hardness, wear resistance, cutting properties and have least ductility. These are

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mainly tool steels. It can be railway rails, laminated springs for railways, wire rope, wheel sponges, saw, mandrels, small forging dies, milling cutters etc.

↳ It can be both hypoeutectoid or hypereutectoid steels.

To enhance different properties of steels, different alloying elements can be added to plain C steel when this addition is more than 5%. We called it as alloy steel. It has various uses.

Stainless Steel

↳ Stainless steels are stainless as they have a minimum of 11.5% Cr in them, which having more affinity for oxygen than iron has, forms a very thin protective and stable oxide film on the surface. This film is continuous, impervious & passive to stop further reaction between steel and surrounding atmosphere.

↳ Stainless steels have become versatile because of it's different properties such as good corrosion and oxd resistance, good creep strength, high resistance to scaling, wide range of strength & hardness, high ductility, good weldability, machinability etc.

↳ Stainless steel is of five types.

a) Ferritic stainless steel
b) Martensitic stainless steel
c) Austenitic " "
d) Duplex " "
e) Precipitation- hardenable stainless steel.

Application of Stainless steel :- Utensils, cutlery items, domestic items, vessels, pipings, heat exchangers, storage tanks (chemical industries), structural materials in nuclear reactor, constructional materials etc.

Different types of Stainless steels :-

Type	Microstructure	Mechanical Properties	Physical Properties
Austenitic Stainless steel	Austenite	Tensile strength: 490-860MPa yield strength: 202-575MPa Elongation in 50mm : 30-60% .	Non-heat treatable, non-magne
Ferritic Stainless steel	Ferritic	T.S. = 410-650MPa Y.S. = 275-550MPa Elongation in 50mm : 10-25%	Non-heat treatable. Good resistance
Martensitic Stainless steel	Martensite	T.S. = 480-1000MPa Y.S. = 275-860MPa Elongation in 50mm : 10-48%	Hardenable by heat treatment
Duplex	Austenite + Ferrite	T.S. = 680-900MPa Y.S. = ~~270~~ 410-900MPa Elongation in 50mm : 10-48% .	Non-heat treatable
Precipitation hardening	Austenite + Martensite	T.S. = 895-1100MPa Y.S. = 276-1000MPa Elongation in 50mm: 10-35%	Hardenable by heat treatment very high Strength

Tool Steel :

Tools are developed based upon their application and property requirement. Tool steel may be defined as special steel which have been developed to form cut on charge in shape of material in to semifinished product. It should have good wear and abrasion resistance, high toughness, resistance to softening on heating etc.

High Strength Low Alloy (HSLA) Steel :

- High Strength low alloy (HSLA) steel is also known as microalloy steel. Microalloy steels are mild steels with carbon 0.03 to 0.15%, Mn around 1.5%, Nb, Ti, V, Al are less than 0.1%, which have been given controlled rolling, to obtain ultra-fine ferrite grains of size below 5µm to attain yield strength of 290-550MPa & tensile strength of 415-700MPa.
- The presence of low carbon i.e. no lamellar pearlite with ultra fine ferrite grains induce high strength and toughness. Good weldability is also due to low carbon in them. The main factors responsible for increased strength in HSLA are (i) fine ferrite grain size, (ii) precipitation strengthening, (iii) solid solution strengthening.
- This type of steel can be heat treated. It can be heated to above recrystallization temp. i.e. 1200°C, so that all alloying elements such as Nb, V, Ti will dissolve in austenite. It will soaked for some time to do homogenization. Then after it can be go through controlled rolling so that it dynamically recrystallizes and grain growth occurs. Ti, Nb form their carbides and nitrides in this duration. At 650-850°C these intermediate precipitate will form and strengthen the alloy. Formation of carbides

and nitrides also restrict grain growth. Hence finer grains produced.

High Speed Steels

↳ High speed steel is one type of tool steel used for cutting purpose. It is primarily developed for making cutting tools.

↳ These steels can be heat treatable to very high hardness, generally the hardness value is 64HRC or more than that. These are not as tough as other steels but red hardness property make them useful for high speed cutting tools of all types such as milling cutter, turning tool, or drill etc. Red hardness is the property that retains hardness at elevated temp. Hardness and toughness is dependent up on Carbon content.

↳ High speed steels can be Cr-based, Mo-based, W-based alloys.

→ W-based alloy: 18% tungsten as amount increases greatly, toughness decreases. Optimum value is 9%. Below 9%, hardenability, wear resistance, cutting ability decreases.

→ V content mostly about 1%. It helps to increase cutting ability. C-content is about 0.7-1.5%.

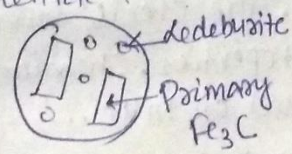
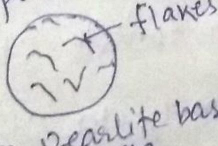
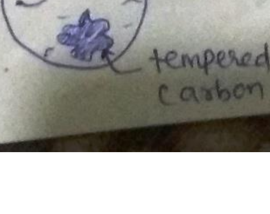
↳ Properties:

(1) Excellent red hardness
(2) Good wear resistance
(3) Good shock resistance
(4) Good non-deforming property.

↳ Application: Cutting tool, drill, taps, power work saw blade, shaper, planner, High temp. bearing, knifes etc.

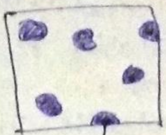
TYPES OF Cast iron, their microstructure

- Cast irons are basically iron-carbon alloys having carbon more than 2% i.e. more than maxm solid solubility of carbon in austenite. These are eutectiferrous iron-carbon alloys i.e. in which eutectic reaction takes place during solidification.
- Theoritically carbon content of cast iron (CI) can lie betn 2.11 – 6.67%, but because higher carbon content tends to make them brittle, the industrial cast irons have carbon normally in the range of 2.11 – 4.0%.
- Cast iron is of 4-types.
  - i) White cast iron
  - ii) Gray cast iron
  - iii) Malleable cast iron
  - iv) Spheroidal graphite cast iron (S.G.)

Types of CI	Microstructure	Properties
i) White CI C - 2.11-6.67% Mostly up to 4.3%	Carbon present in combined cementite form 	Higher hardness, strength at higher temp., abrasion resistant, brittle
ii) Gray CI C = 2.4 - 3.8% Si = 1.2 - 3.5% Mn = 0.5 - 1.0% S - 0.06 - 0.1% P - 0.1 - 0.2%	Free form of carbon Graphite flakes  on pearlite base or ferrite	High compressive strength, rigidity, form sound casting easily machined, self damping, self lubricating. wear resistance
iii) Malleable CI C = 3.0 - 3.7% Si = 0.4 - 0.9% Mn = 0.2 - 0.4% S = 0.3 max P = 0.1 max	Ferrite matrix and tempered carbon 	High yield strength, Young's modulus, low CTE, good wear resistance

iv) Spheroidal Graphite Cast iron

Mg = 0.04-0.06%
Ti = 0.1%
Pb = 0.009%
Bi = 0.003%



Graphite spheroids nodules
(Matrix may be ferrite or pearlite)

Excellent castability, wear resistance, good machinability, damping capacity, intermediate betn cast iron & steel

Typical Uses Specification of Steel

↳ After a steel has been designed for a specific application, the designer, or the purchaser has to select the specific steel from those available in the market. The steels are sold with standard specifications and associated notations. Some specification knowledge thus essential. The chemical composition, mechanical properties, hardenability, method of manufacture, nature of applications, etc.

Indian Standard Specifications:

↳ In Indian Standard Specifications, for the purpose of code designation, the steels have been classified on the basis of properties, chemical composition though mainly it is based on latter.

(a) Code designation based on Mechanical properties:
It uses the tensile strength, or yield strength for designation.

Fe = minimum tensile strength in N/mm^2

Fe E = minimum yield strength in N/mm^2

Example

Code designation	Meaning
Fe E 210	Steel with minm y.s. = 210 N/mm^2
St E 250	Steel with minm y.s. = 250 Kg/mm^2
Fe 310 K	Killed steel with minm t.s. = 310 N/mm^2

(b) Code designation based on chemical composition :-
The carbon content of steel is specified as numerical figures called carbon points, where one point of carbon is defined as 0.01%. Letter 'C' is used for plain carbon steel and 'T' for tool steel.

Example Specification Code	Average Composition of elements
C15	C = 0.15 %
30C5	C = 0.30 %, Mn = 0.5%
37Mn2	C = 0.37%, Mn = 2.0%
55Mn75	C = 0.55, Mn = 0.75%

AISI / SAE specifications :

↳ The American Iron and Steel Institute and Society of Automotive Engineers have cooperated together, and thus have similar specifications based on chemical composition of steels. The specifications normally have four numerical digits (in some cases five). Any letter prefix to it is the method used in steel making.

A = Alloy steel, basic open-hearth Process
B = Carbon steel, Acid-bessemer
C = Carbon steel, basic open hearth
D = Carbon steel, acid open hearth
E = Electric furnace steel

AISI A XX XX

- XX (last two) → Indicate carbon points
- X (second) → Added element
- X (first) → % of main alloying element
- → Type of steel
- A → Letter indicates method of steelmaking

First digit from left	Type of steel
1	Carbon steel
2	Ni- steel
3	Ni-Cr steel
4	Mo steel
5	Cr steel
6	Cr-V steel

7 W. steel

8 (Triple alloy steel) Ni-Cr-Mo (low) steel

9 Si-Mn steel

British Specification:

↳ British specifications for steels used to be designated by letters 'En' followed by a number. This no has no relationship with either composition or mechanical properties of steel.

↳ First three digits for content of alloying elements, followed by a latter A, H or M, which means Analysis based, Hardenability based or Mechanical properties based specifications respectively. The last two digits after this is meant for carbon points.